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THESIS

USING THE GLOBAL POSITIONING SYSTEM (GPS)
TO FULFILL
THE POSITION/LOCATION REQUIREMENTS OF
THE NATIONAL TRAINING CENTER (NTC)
AND OTHER U.S. ARMY INSTRUMENTED TEST-
ING AND TRAINING RANGES

by

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March 1991

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And Other U.S. Army Instrumented Testing And Training Ranges

by

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Major, United States Army
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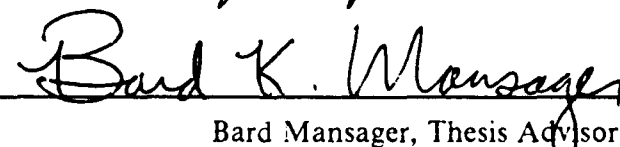
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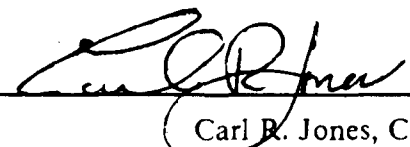
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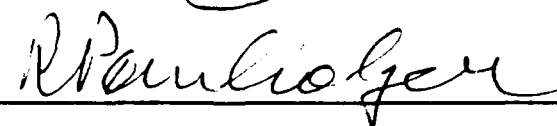
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ABSTRACT

This thesis discusses the use of the Global Positioning System (GPS) to fulfill requirements for exact position location (P.L.) of combat elements on Army testing and training ranges. These requirements include the control of the ranges, measuring effectiveness of employing new systems or doctrine, use in after action reviews (AARs) to discuss battlefield events, recording operations for later analysis, and safety. It also addresses use of GPS equipped systems by the player units while participating in simulated combat on these ranges. The National Training Center (NTC) at Fort Irwin, California, is currently the largest and most complex of the Army's instrumented ranges. It is referred to throughout this thesis for examples of P.L. requirements and instrumentation capabilities.

The development and fielding of GPS has added a new dimension in the Army's ability to accurately measure and record P.L. The designers of future instrumentation upgrades are incorporating GPS capabilities. This thesis will show how capabilities can be improved and money saved by using a coordinated effort when employing GPS on the Army's instrumented ranges.

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I. INTRODUCTION

A. EXECUTIVE SUMMARY

Since the initial use of combat exercises to train individuals soldiers and units for war, trainers have had requirements for an accurate position/locating system to aid in the task of keeping track of the many wargame players and controllers on the simulated battlefields. One of the primary Army achievements in meeting this challenge has been a fifteen year effort to construct and operate instrumented testing and training ranges. An instrumented range uses an automated system to track the exact locations and actions of the participating combat elements. They improve the quality of simulated combat needed in testing Army equipment and training Army units. Such ranges are now in operation at various Army installations throughout the world. The goal of these ranges is to provide the most realistic combat environment possible with the ability to track and record exactly what transpires on the simulated battlefields. The record capability allows combat trainers to show player elements, at the end of the exercise, battlefield details that would have otherwise never come to light in the heat of the simulated combat.

The launch and deployment of the Global Positioning System (GPS) has brought the world of navigation and position locating systems to the edge of a new and greatly expanded capability. The Army is just now developing many new combat and training systems that will take advantage of GPS capabilities.

It is the intent of this thesis to address the future use of GPS on instrumented testing and training ranges. It addresses GPS use on these ranges in two main areas; 1. Use of GPS to satisfy the position/location needs of the instrumented range in running and controlling simulated combat exercises, 2. Use by player units in training to a new position/location capability that will be used in future combat. Because most instrumented ranges have similar position/location requirements, This thesis will use the largest of the Army's instrumented ranges, the National Training Center at Fort Irwin, California as a basis for discussion but will also address the differences in mission and use of other instrumented ranges. This thesis is broken down into seven chapters:

- Chapter I contains this introduction and a statement of purpose and scope.
- The first part of Chapter II will address the differences between the use of position/location on instrumented ranges for testing control and evaluation, training control and evaluation, and combat unit use. It will show that, other than the degree of location accuracy and number of instrumented elements used, there is little difference between position/location requirement of testing ranges and those used for training. It will also propose that vehicles held for use at instrumented ranges and already equipped with a GPS capability, could use GPS receiver input to feed several subsystems requiring position/location data. This would allow a single GPS receiver to fill the requirements of both the control systems and the combat systems. This idea will be expanded upon in later chapters. The rest of Chapter II gives the background information needed to understand the purpose and function of:
 1. Army instrumented ranges in general
 2. The National Training Center which will be used as a specific example
 3. The Global Positioning System.
- One of the main objectives of this thesis is to more firmly establish the position/location requirements to run and control combat exercises on instrumented ranges. Chapter III contains the research and experience of fifteen current and former observer/controllers at the NTC in establishing these requirements. This information is important in determining the required accuracy and timeliness needed from GPS based equipment in servicing range requirements.
- Chapter IV addresses how the requirements for position/location in running an instrumented range could be filled using a GPS based system. It compares the current Remote Measuring System (RMS) to a possible GPS based system. It does this in terms of:
 1. COST
 2. SPEED
 3. ACCURACY
 4. MOBILITY
 5. AVAILABILITY

6. COMPLEXITY

- The intent of Chapter V is to establish the fact that GPS will be used on instrumented ranges by player units. It will show that there are many systems and functions that appear on simulated battlefields that will use GPS input. Chapter V also contains the results of an initial use of GPS by a player unit at the NTC. The use of GPS by player units and the use of GPS in the control system of an instrumented range are currently being thought of as two separate issues by system designers. Herein lies one of the main points of this thesis; there is a potential for combining these requirements into a single set serviced by a single GPS receiver. Chapter V also discusses the issue of GPS use by mock Soviet equipped Forces.
- The decision problems explicitly addressed in this thesis are:
 1. Should GPS capabilities be exploited to fulfill P/L requirements on Army instrumented ranges?
 2. Is there an efficient way to field GPS based systems used to support Army testing and training ranges?
 3. Are requirements at the various ranges similar enough to recommend standardization of GPS equipment?
 4. Should player units be provided with on-board P/L if available?

Chapter VI contains the conclusions and recommendations. Even if there is some disagreement with this chapter, by this point in the thesis, it is hoped that the reader will understand enough of the background and issues to produce an educated argument for or against the main points. The main points of the conclusions and recommendations are:

1. GPS will inevitably become the main provider of position/location input into the control systems of Army instrumented ranges. This will happen sooner rather than later and is, in fact, already planned for at some locations. Further expenditures for the older RMS system except to maintain current capabilities until replaced by a GPS based system would be a waste.
2. A more coordinated effort needs to take place in the production of GPS based systems that will be used on instrumented ranges. At present, costly duplication of effort and overlapping capabilities is the road being traveled. A single GPS produced position/location should be used to feed multiple requirements.
3. Multiple ranges with different systems is unnecessary, confusing and expensive. Again, a more coordinated approach with decision makers from all instrumented ranges meeting and coordinating efforts is a better way.

4. Player unit needs must also be factored in when addressing the position/location requirements on instrumented ranges. Availability and accuracy of GPS equipment in training will effect future use of GPS products in combat. Commander of combat units that train on instrumented ranges need to state desires for use of GPS capabilities.
5. Instrumented ranges will be the place where soldiers and leaders learn to effectively integrate GPS capabilities into combat operations. The lesson learned through time that "a unit fights as it trains" provides special impetus to the accelerated incorporation of GPS into combat exercises.

B. PURPOSE AND SCOPE

This thesis is not intended to address all possible implementations of GPS in conjunction with Army testing and training ranges and use by combat units. It does, however, cover major functions where using GPS capabilities could contribute significantly to range control, testing, and training. This thesis will point out that GPS is much more economical than the current system. It can provide P/L in more locations, with more reliability and capability. This thesis will show that there is great potential for developing a GPS based system to provide a transportable range instrumentation system that would be of great value to units deployed to areas where they do not have access to an instrumented range. It also points out that there are a variety of P/L requirements currently being managed by different agencies proposing the use of GPS based systems. Most of these systems are in the early stages of development. This thesis will suggest that there needs to be a coordinated effort to develop a common system to satisfy multiple P/L requirements. Now is the time to act to prevent a large duplication of effort.

II. BACKGROUND

A. U.S. ARMY INSTRUMENTED RANGES

1. GENERAL

Instrumenting a combat simulation range means to equip it with the necessary data gathering and display equipment to allow operators to monitor, control, and record battlefield activities.

One of the main capabilities that makes any instrumented range work is the ability of the Central Instrumentation System (CIS) to know the exact location of all vehicles and maneuver units at any given time during the battles. Not only is this information available in real time, but it is also recorded for later evaluation and training. Range instrumentation systems, currently in use, provide this position location (P L) using an expensive ground based system of fixed receive stations. These stations process signals transmitted by each vehicle or weapon system. Instrumenting a range is a time consuming, maintenance intensive and costly endeavor but has proven well worth the resources required. Army ranges are instrumented for two basic purposes; testing and training. Both kinds use instrumentation to control simulated combat, however, testing ranges tend to need more accurate location information on fewer elements while training ranges are usually happy with less accuracy provided for more elements.

a. Testing

The mission of range instrumentation, when testing Army equipment and doctrine, is to provide an environment where extremely accurate readings can be taken and recorded without disrupting the simulated combat. In the past, just producing a realistic combat environment was a difficult challenge. Trying to take necessary readings "on the fly" or stopping the battles to make data evaluations, led to a large probability of error. This did not produce the accuracy desired when testing important equipment or doctrine. The first instrumented testing range to become fully operational was the TEXCOM Experimentation Center (TEC) at Fort Hunter Liggett, California. Instrumented testing ranges like TEC, allow a high degree of realism while also providing a system for accurately measuring and recording data.

b. Training

The mission of instrumented training ranges are similar to those stated for testing ranges. They provide a location where battalion and brigade size units can fight battles against a highly trained opposing force, in a realistic environment, without seriously endangering soldiers. The intent of these ranges is not to grade individuals or units, but to provide a free play exercises (maneuver and live fire) where mistakes can be made, learned from and corrected; where soldiers can lose a battle but live to learn the lessons that might keep them alive in actual combat. As with instrumented testing ranges, battlefield data is accurately taken and recorded. This is done, not only to control the simulated combat, but to provide a tool to use when determining how to improve unit capabilities. The National Training Center (NTC) at Fort Irwin, California was established in 1980 and is the largest instrumented training facility in the world. It is used to train ground forces and the units that support them. The NTC will be referred to throughout this thesis. It will be used to provide examples of instrumentation requirements.

2. Combat Unit Use Of P/L

Army commanders throughout history have desired to obtain a more timely and accurate locating capability that would allowing them to know the exact location of friendly forces and subordinate units. Individual soldiers on today's highly lethal and fast moving battle fields also have an expanded need to keep track of there own exact location. Accurate locating systems increases a combat units ability to coordinate complicated battlefield maneuvers, render accurate direct and indirect fires on enemy locations, and maintain positive command and control over subordinate elements. army testers and

The recent development of the Global Positioning System (GPS) has caused Army system developers to consider using this system to provide P/L on instrumented ranges. They also expect the proliferation of GPS based navigation, command and control equipment to cause extensive use of these systems by units that deploy to these instrumented ranges. Instrumented ranges have the unique potential of incorporating the more economical GPS to fulfill P/L requirements for combat simulation control and, additionally, training combat units to effectively employ GPS capabilities. To be able to fill both the requirements of the range operations and the combat units maneuvering there with input from a single GPS receiver would be desirable.

3. TEXCOM Experimentation Center (TEC) And Early Development Of Instrumented Ranges

In 1977 General Dynamics Corp. was awarded a ten million dollar Army contract to build a range measuring system (RMS) as a part of the effort to instrument ranges at Fort Hunter Liggett, California. [Ref. 1] This system is used to aid test and evaluation of new equipment and doctrine, the mission of the Army's Test and Experimentation Command (TEXCOM). The facility at Fort Hunter Liggett is called the TEXCOM Experimentation Center (TEC).¹ The mission of TEC is to provide an instrumented area where Army units can fight simulated battles, under realistic conditions, utilizing the new equipment or doctrine to be tested. The exact status of each combat element can be determined at any point in time and recorded for evaluation. Although the entire battle simulation and instrumentation system is a complex system of weapons effects simulators, logistics and orientation analyzers, and observer/controllers, much of what makes the whole system work is knowing the exact location of each combat element at any time during the battle. This is what the RMS provides.

In simple terms, the Range Measuring System produces a "fix" on each element participating in the simulation. It uses permanent ground stations, called "A" stations, placed on high ground throughout the range.² These solar powered stations receive signals from "B" unit transmitters located on each instrumented vehicle, aircraft or manpack. The "B" units transmit the exact time which, when received by three or more "A" stations, is used to calculate a location. The calculation is based on time difference of arrival (TDA). [Ref. 2] The "A" stations must be accurately surveyed to produce an exact location. It takes at least three "A" stations in direct line of sight of the "B" unit for a location to be derived. Once the signal is received and a "B" unit is identified, the information is transmitted to a "C" station which is located on the highest ground on the range. The "C" station has line of sight with all "A" stations and acts as a relay for all the information collected by the various "A" stations, transmitting the data to the Central Instrumentation System (CIS). There, the information is turned into accurate P/L for each "B" unit.³ The original RMS system, currently used at Fort Hunter Liggett, was so successful that it became the forerunner of several of its kind which have been built throughout the Army. (see Appendix A)

¹ Some of TEC's administrative offices are located at Fort Ord, California.

² TEC uses 87 "A" stations to cover the range.

³ There are also "D" stations which are data relays, used when line of sight is a problem.

4. DEVELOPMENT OF POSITION/LOCATION AT THE NATIONAL TRAINING CENTER (NTC)

Only a few years into the development of the RMS at Fort Hunter Liggett, the Army started designing and building a National Training Center at Fort Irwin, California. Using TEC as a model, developers of The NTC envisioned a large, fully instrumented, training range. At this center, however, the emphasis would not be on testing newly developed equipment or doctrine, but on training units, of brigade and battalion size, with the equipment and doctrine already in use throughout the Army.

Developers of the NTC established many of the same requirements for P/L that existed for the range at Hunter Liggett. To satisfy these requirements, a larger version of RMS was developed and built to support the NTC. This system functions in much the same manner and with much of the same equipment as does the system at Hunter Liggett. However, because the NTC is so large, over three times the number of "A" stations were needed to cover the massive range at Fort Irwin. These "A" stations feed into two "C" stations located at the top of the two highest mountains at Fort Irwin.

After the employment of the RMS at the NTC, several other ranges across the Army were instrumented (Electronic Proving Grounds at Fort Huachuca, AZ; Ranges at Fort Bliss, TX; Yuma Proving Grounds, AZ; Hoensfeld, West Germany; and several others to a lesser extent) but the instrumentation of the National Training Center at Fort Irwin remains, by far, the largest. It provides constant P/L for over 500 U.S. and Opposing Forces (OPFOR) player vehicles, aircraft and ground elements.⁴

All instrumented ranges in the Army, whether used for testing or training have similar requirements for P/L. Generally, the testing community needs more accurately measured data from fewer elements, whereas, the training ranges, like the NTC, want more elements to be instrumented but do not require highly measured locations (locations to within several meters rather than tenths of meters). The basic requirement for constant, accurate P/L, however, exists in both cases.

Because the National Training Center is the most extensive of all the instrumented ranges in the Army, its requirements for P/L will be used throughout this thesis as examples of general P/L requirements which apply on any instrumented range.

⁴ Between the Army and Air Force, there are now over 25 instrumented testing and training ranges for ground forces, some much more extensively instrumented than others.

B. THE NATIONAL TRAINING CENTER TODAY

1. Background

The NTC covers more than 1000 square miles, almost as large as the state of Rhode Island. It is the largest maneuver live fire training facility used by any of the U.S. Armed Forces. Fort Irwin is located in California's Mojave Desert, near Death Valley. This makes it a perfect place for training units in desert warfare. However, using terrain which only reflects desert combat conditions has drawn some criticism when the cost of the NTC is discussed. The initial cost of the NTC was \$260 million and has cost over \$20 million per year to maintain. A unit deploying to the NTC may spend as much as an additional \$3 million in transportation and maintenance costs for a four week rotation. In spite of the relatively high cost, the National Training Center is the most highly utilized training facility in the world. It is primarily used for training combat units but some field tests have been conducted in conjunction with maneuver unit rotations. New equipment is constantly being brought to the NTC by the training units as it is fielded to them.

The NTC provides a realistic combat environment for all types of maneuver units and their support elements. Armor, mechanized infantry, and even light infantry units find the NTC the best training experience ever afforded them. They consider this time spent in the desert the most intensive, yet most valuable, preparation for actual combat they have received. Brigade and battalion size units from throughout the U.S. come to the NTC for three to four weeks of simulated combat. Training at the NTC includes a Maneuver phase and a Live Fire phase. Of the four weeks most units spent at the NTC, one week is used in logistics (moving to and from Fort Irwin, drawing and turning in equipment, and on the ground preparation for deployment), two weeks in Maneuver training, and one week at Live Fire. Most units consider the maneuver phase the most intensive because they fight against a live opposing force, the OPFOR.

Besides providing excellent training for FORSCOM ⁵ units, the NTC also produced a virtual flood of information which is continually being analyzed to improve the effectiveness of operations, tactics and equipment throughout the Army. There are many sub-components that go into making the NTC such a valuable training center. It is a large effort just getting the training units to the NTC and providing for them while they are on station. Support units find the considerable logistical challenge the best

⁵ Forces Command, comprised of most U.S. based Army combat units

training for actual combat they receive. The three main components that provide the foundation for the NTC training experience are:

- The instrumented training range
- A highly trained and well equipped Opposing Force (OPFOR)
- Qualified Observer/Controllers (OCs)

2. Instrumentation

Because the maneuver interaction at the NTC is the most realistic, "free play" oriented training ever attempted by ground forces, each combat system, as well as each soldier, is required to be highly instrumented. The Multiple Integrated Laser Engagement System (MILES) provides realistic simulation of weapons engagements. Each weapon system, as it is fired, gives off a battlefield signature such as flash and bang provided by an onboard, pyrotechnic device. It also emits a laser beam with a code particular to that type of weapon. If the beam hits one of the small sensors placed in several locations on each vehicle or soldier, a small black box ⁶ determines if that weapon which fired at it would have any effect. When hit, an audible and visual signal is automatically turned on indicating that the person or system has been disabled or destroyed. The "hit" system's weapons will then no longer function.

Besides MILES, the NTC employs a number of "Fire Markers". These personnel move across the battlefield in specially equipped vehicles with the mission to provide the simulated battlefield effects of indirect fire. They accomplish this using a large number of pyrotechnics. Even with this effort, realistic replication of indirect fire remains the weakest link in the simulation.⁷ The battlefield effects at the NTC have, however, have been rated the best in the world. They provide a realistic environment for combat training.

The range instrumentation, which monitors the location and actions of all vehicles and dismounted infantry forces, provides more than just the location of each element. A complete record of where each weapon system is oriented, when it fires and who it fires at, is also made. Additionally, the instrumentation personnel have the capability to record, on video tape, a visual record of the battle from several angles and distances; on audio tape, radio transmissions during key events. Much of this data

⁶ part of the MILES system

⁷ There are plans to upgrade indirect fire using a GPS based system addressed later.

would be impossible to gather and evaluate without the range instrumentation system. This instrumentation makes possible the collection, real-time display, and recording of a large variety of battlefield data for later analysis.

Most of the vehicles and heavy equipment used by the U.S. forces and the OPFOR are kept and maintained, under contract, at Fort Irwin. This allows the vehicles and equipment used at the NTC to remain fully instrumented. The contractors that maintain the equipment remain on station at Fort Irwin. They are usually able to keep above a 90% operationally ready rate on instrumented vehicles. Contact teams go to the field before each battle to fix or replace any non-operational equipment. Before a vehicle is allowed to participate in a battle, the instrumentation on each vehicle and weapon system is checked. The OCs will pull it from the battle if its MILES is not fully functional or accurate P/L can not be established.

3. The Opposing Forces (OPFOR)

The NTC also utilizes an on station, mock, "Soviet type" force. This force is fully equipped with mock and actual Soviet⁸ vehicles, weapons and equipment.

The Opposing Force (OPFOR) is made up of elements of the U.S. 177 Armor Brigade which task organizes to, as closely as possible, replicate a Soviet Division comprised of two Motorized Rifle Regiments and a Soviet Tank Regiment. Other Soviet divisional support elements such as Radio Electronic Combat, Engineer support, and Tactical Air support are also replicated.

As important as the range instrumentation is to the NTC, training at Fort Irwin would not be worth the trip if it was not for the OPFOR. The experience of fighting a highly trained adversary, equipped with Soviet equipment and doctrine, is unequalled in the Army. Because the OPFOR trains every day, fighting units on the battlefields of the NTC, many consider it to be the best trained combat organization in the world. The OPFOR is also instrumented and equipped with MILES. OPFOR leaders conduct evaluations after each battle in a constant effort to improve the OPFOR's capability to fight the U.S. forces that face it. One other value of having an OPFOR comes when soldiers leave Fort Irwin, usually after a 3 to 4 year tour. They go back out into the "real" Army with a much better understanding of how the Soviets fight.

⁸ includes other Warsaw Pact equipment and weapons

4. The Observer/Controllers (OCs)

The Observer/Controllers (OCs) work hand in hand with the chain of command of both the NTC and the player units to insure quality training and safety. They are usually senior captains, majors and lieutenant colonels who have been in command and can relate to the training unit's needs. The goal of the OCs is to observe as much as possible and control as little as possible. This insures the maximum amount of "free play" within safety limits, while also insuring the ability of the OCs to lead the training unit through meaningful after action reviews. AARs are conducted at the end of each battle to discuss unit strengths and weaknesses. There are actually two sets of OCs; one set on the ground with the training unit⁹ and one set which works at the CIS. Each OC in the field has a counter part in the CIS. The field OC can observe, in person, what is actually happening on the ground. The OCs in the CIS watch and record the larger picture of what each element is doing in relation to the entire battlefield. The OCs work together to insure that, after the battles are over, an accurate picture of how and why each element failed or succeeded, can be graphically depicted to the training units. It is easy to see why the OCs are one of the primary users of P/L at the NTC.

5. After Action Reviews (AARs)

One of the major training values of the NTC's RMS is the ability it gives the Observer-Controllers to conduct AARs at the battalion level. The key commanders and staff from both sides, along with the senior observer controllers, gather together at the end of each battle to discuss the events of the operation; what went wrong, what was done correctly and why. This training session is greatly aided by the OCs' ability to play back a large, projected, computer image of exactly where all elements, from both sides, were at any time during the conduct of the operation. Many potential arguments over what happened in the heat of battle, are avoided when actual locations can be depicted. These AARs have helped the maneuver battalions within FORSCOM reach a higher level of training than ever before. According to the OCs, "They could never have happened without accurate P/L and the ability to record it."

6. Major Commands With Interests At The NTC

Many different Army commands, as well as other services and organizations, have vital interests at the NTC. Units that come to train at the National Training

⁹ usually one per company sized element and larger and one for each staff element

Center, and the OPFOR that opposes them, fall under Forces Command (FORSCOM). The actual training program and the OC teams who oversee the training of the visiting FORSCOM units are assigned to the Training and Doctrine Command (TRADOC). Although The OPFOR utilizes mostly U.S. vehicles and equipment which have been modified to look and function like Soviet vehicles and equipment, the Intelligence and Security Command (INSCOM) maintains a small fleet of actual Soviet and Warsaw Pact vehicles and weapons. They are also instrumented and participate in the maneuver operations with the OPFOR. Many of the other major commands in CONUS, though not actually represented on location at the NTC, play a significant role. These units are mostly involved in transportation, logistics or other support aspects of the NTC.

Training also incorporates one half of all CONUS tactical air sorties flown by the Tactical Air Command (TAC). Close air support is flown in support of the training unit and the OPFOR. There are Air Force representatives on the ground that deploy to the field during each battle to insure proper coordination. Air Force aircraft that participate are instrumented and subject to being shot down by air defense forces. The Marine Corps also brings maneuver units to the NTC to train on a regular basis. The battlefields of the NTC truly reflect the joint nature of a major training center and the need for compatible equipment.

7. Change And The Future Of The NTC

Although everyone involved with the NTC has nothing but praise, each agency has a different idea on how to make the training fit their particular requirements more effectively. This provides a challenge when addressing upgrades to the instrumentation system or any other part of the NTC.

Additionally, thanks to the OCs, OPFOR and the instrumentation system, battle simulations, far more realistic than any others carried out before, are now an every day event at Fort Irwin. For this reason, changing this highly successful combination in any way is scrutinized with great care and some scepticism. Change, however, is in the future and has taken place as upgrades in software and hardware are currently being implemented to improve the overall operating system. There have been discussions for some time about the future size of the OPFOR, as well as the size of the training maneuver unit. ¹⁰

¹⁰ Full brigade size operations are now limited.

Additionally, the proliferation of specialized training centers with their own instrumentation has taken place over the last 5 years. This include the development of the Joint Regional Training Center (JRTC) at Fort Chaffee, AR, for training Light Infantry units. The instrumentation of Hoensfeld, West Germany¹¹ is currently under development. It incorporates the ideas of the NTC but includes an upgraded P/L system. Other ranges at major maneuver unit locations, like Fort Hood, TX, are also being instrumented to provide simulated combat training without having to travel to the NTC.

A major request for proposal (RFP) is scheduled to be released from PM TRADE¹² in October 1990 for an upgraded instrumentation concept called Mobile Automated Instrumentation Suite (MAIS).¹³ This system may have a dramatic impact on the use and capabilities of all instrumented training ranges. It is envisioned that this system will not be tied to a specific location like the NTC.

a. LEAD-IN TO GPS

The NTC is currently utilizing the ground based Range Measuring System to maintain P/L on over 500 individual vehicles, aircraft¹⁴ and ground force units simultaneously. This information is fed directly into the main computer control center at the CIS building¹⁵ and processed for use. As stated, the function of knowing where all elements on both sides are at all times, is considered to be one of the most vital at the NTC. This holds true for both control and analysis. The current location system, though very functional, has shortcomings in speed, cost, accuracy and coverage. This thesis will show that GPS can help overcome these weaknesses. Incorporation of GPS into the NTC and other testing and training facilities, to provide P/L, is already foreseen by the Army. One of the main ideas explored herein is the importance of making the incorporation of GPS a coordinated effort with a smooth transition. Many questions on the best way to utilize GPS capabilities, as an effective asset for the NTC, remain.

¹¹ Hoensfeld has been used for maneuver and live fire training by U.S. forces in USAREUR for many years without any form of instrumentation. The newly instrumented center at Hoensfeld is called the Combined Maneuver Training Center (CMTC).

¹² Program Manager for Training Devices, involved with procurement of all training devices used through out the Army and the coordination with other services and agencies for commonly used systems.

¹³ MAIS requires GPS interface

¹⁴ rotary and fixed wing

¹⁵ The Central Instrumentation System is sometimes called the "Starwars" building because of its impressive complexity.

b. GPS WILL COME TO THE NTC WITH PLAYER UNITS

Within two years, major fielding of GPS supported systems, designed for combat navigation, command and control, will take place. These systems will, soon afterwards, start appearing in units throughout the Army, Air Force and Marine Corps. It is only natural to think that these systems will be brought to the NTC for use in providing P.L. to player units. The NTC will be a prime location for assessing the usefulness and deficiencies of these systems. Soldiers and leaders alike will explore new applications of a long desired capability.

C. GLOBAL POSITIONING SYSTEM

1. HISTORY OF GPS

Navstar Global Positioning System (GPS) is a constellation of satellites which provides radio-positioning, precise time, time interval transfer, and Nuclear Detection (NUDET) capabilities. All of these capabilities, except for NUDET, are applicable to the instrumented testing and training ranges of the Army.

GPS was initially conceived in 1973 when the Deputy Secretary of Defense created the GPS Joint Program Office. The U.S. Air Force was placed as the lead agency but the Army, Navy, Marine Corps, and Defense Mapping Agency played active roles in the system's acquisition. The system, though military in nature, was also foreseen to have numerous civil applications as well.

GPS was intended to combine the best elements of two competing systems; the Navy's TIMATION, and the Air Force's 621B program. TIMATION was only a two-dimensional system, and 621B required at least four separate satellite constellations, each with its own ground stations. Each of these systems were limited in scope and capabilities. When it was decided that the programs needed redefinition, man years were spent insuring that the requirements from all potential users were considered in the new design. Input was taken from all the services. From this input, it became obvious that the military wanted a system that would support both testing and training as well as operational requirements. It took five years of further development before the first satellite was launched in February, 1978.

The original design configuration of the NAVSTAR system called for 24 satellites in three orbital planes, with projected 10 meter accuracies. The configuration, as now planned, will consist of 18 operational satellites plus three on-orbit spares. Con-

tinuous worldwide coverage is made possible by arranging the 18 satellites in 6 different circular orbital planes. projected lifetime of each satellite is 7.5 years. To date, 20 satellites have been launched. There are currently 17 operational Block I and Block II GPS satellites in orbit.¹⁶ Not all are totally functional. (see Appendix C) The latest deployment schedule calls for one satellite launch every 90 days¹⁷ with the system becoming fully operational (18 active satellites plus on orbit spares) in 1992. Original cost estimates for the entire system were \$1.17 billion in 1973 dollars. Current launch costs are \$65 million per satellite and \$30 million per Delta 2 booster.

Military applications of a fully functional GPS system are numerous. GPS will significantly enhance military aviation by providing highly accurate independent location, navigation and targeting data, as well as non-precision instrument approach procedures. Ground forces can link up and coordinate their activities more precisely. Precision weapons delivery will be much easier. Artillery units will realize improvements in emplacement, registration and target handoffs. Intelligence systems will be able to more accurately locate and identify enemy forces. Search and rescue,¹⁸ will be more efficient and could save lives in time sensitive situations. These are just a few of the planned applications of GPS. The Joint Program Office in Los Angeles has a 200 page book listing the proposed military uses of the GPS system.

2. GPS SEGMENTS

In its current configuration, GPS has four segments: a space segment, a control segment, a user segment, and a NUDET segment (not at issue in this thesis). All of these segments work together, thus, the degradation of one means the degradation of the resulting positioning product.

The space segment is, by nature, the most costly and complex part of this system. When fully deployed, the 18 operational satellites constantly transmit navigation position and time-transfer signals on two L-band frequencies, 1575.42 MHz (L1) and 1227.6 MHz (L2).¹⁹ To maintain the capability of transmitting the accurate time required for the system to work, each satellite has an on-board cesium beam atomic clock

¹⁶ Block II satellites have an improved atomic clock for improved reliability.

¹⁷ next launch scheduled for 29 Sep 1990

¹⁸ a reoccurring event at the NTC in MEDEVAC operations

¹⁹ For applications at the NTC or at TEC, rules of engagements will necessarily have to address spoofing and jamming of GPS signals.

which can provide accuracies of 1 second every three million years. These signals must be received and processed on the ground by a user set.

The user segment consists of several different types of receiver/processor sets. Each type is uniquely configured for its intended mission. Military applications vary from low-dynamic, man-portable sets to high-dynamic sets for high-performance aircraft.²⁰ Commercial sets are already in full production and in use throughout the world. All sets must be able to receive the encoded information transmitted by the space segment and process it to produce an accurate location. The information received includes the location of the transmitting satellite, derived from its orbital parameters, and the exact time the signal was sent. Comparing several readings from one satellite or one reading each from several satellites, the receiver produces a location.²¹

The control segment provides tracking, telemetry, and control (TT&C) functions for the system. It also uploads critical information on time, satellite position, and constellation status. Without the control segment, the satellites would continue to function, but the data produced would become increasingly inaccurate until the entire system was useless. The control segment is made up of a master control station, five monitor stations, three ground antennae, and a prelaunch compatibility station. The monitor stations passively track all satellites in view to accumulate ranging data. The ground antennae pass updated navigation messages from the master control station to the constellation. The prelaunch compatibility system ensures that each new satellite is operating properly prior to launch.

3. GPS ACCURACIES AND COVERAGE

When fully operational, GPS will be the most accurate and reliable location and navigation system in the world. In addition to accurate location, GPS's full capabilities will include velocity and altitude produced by high-dynamic sets. Accuracies of these products is highly dependent on the precision of the clocks in the satellites and the user sets. Though the satellites have atomic clocks, user sets are usually equipped with much cheaper quartz oscillators. GPS permits these quartz clocks to approach the cesium clock accuracy by comparing several time readings and applying a correction factor. This system works well for stationary sets because the correction factor calculation only

²⁰ A variety of types are expected to soon be seen at the NTC and other centers.

²¹ It is possible to get a fix from just one satellite. However, a satellite's position is not known with absolute accuracy. A single-satellite fix cannot have the precision of a multi-satellite fix.

needs to take into account the change in time and the change in location of the satellite. Both of these are known constants. When the receiver is also moving, the added dimension of complexity hinders the effective calculation of the correction factor. The user sets compare signals from up to four satellites with their known orbital parameters and use this information to determine the user's position, velocity, time, and altitude with an extremely high degree of accuracy.

GPS can attain accuracy levels far better than any other system now in use: [ref. 3]

Table 1. GPS ACCURACY

POSITION	16 METERS SEP (spherical error probable) under worst jamming conditions.
VELOCITY	.1 METER SECOND
TIME	.1 MICROSECOND

GPS has numerous advantages over other military and civilian location navigation systems. Its most important military aspects are its availability to virtually unlimited number of passive military users, its worldwide coverage,²² and its all-weather capability. A comparison of these capabilities with established navigation systems highlights GPS's superiority.

Additionally, GPS will provide its most accurate services only to authorized users. In order to prevent enemy use of GPS capabilities, access codes to the most accurate GPS data will be controlled by Department of Defense (DOD). The accuracy can also be

²² GPS gives continuous world wide coverage with only limited areas and times of degraded service, none of which effect the NTC or other major centers. Unlike the current ground based system at the NTC which can be affected by loss of line of sight with one of the three ground based "A" stations required for accurate location, a GPS based system will provide locational information at virtually any spot at Fort Irwin based only on the operational status of the onboard unit.

Table 2. DEFICIENCIES IN CURRENT SYSTEMS

LORAN-C	LIMITED BY SKYWAVE INTER-FERENCE
OMEGA	SUBJECT TO VLF PROPAGATION ANOMALIES
INERTIAL NAVIGATION SYSTEM (INS)	DEGRADED PERFORMANCE OVER TIME (DRIFT)

intentionally degraded by the control stations. This would be done only if enemy use was detected and deception considered more important than friendly force access.

There are two different basic accuracies available from GPS represented by two separate coded messages. Each satellite transmits both codes. These codes are the Coarse Acquisition Code (C/A-Code or C-Code)²³ and the Precision Code (P-Code). C/A-Code will be available to anyone. It is relatively easy to pick up, since the receiver only has to synchronize with a repeating code one millisecond long. However, C/A is limited in accuracy and in some contingencies could be deliberately skewed even further.²⁴ The P-Code will be available to Department of Defense authorized users only. It is a very long code with a high data rate making it much more difficult for tactical receivers to pick up directly. Receivers using the P-Code will, therefore, be much larger and complex than the ones using the C-Code. A technique for ground application of the C/A-Code, called "Differential Correction", has been developed to greatly improve the accuracy of this code. Highly accurate survey points are used to develop a local correction factor that can be applied to receivers in the area. Using this method, accuracy of less than a meter can be achieved using the C/A-Code.²⁵

The receivers used in conjunction with GPS have several modes. In the acquisition mode, the receiver "searches the sky" for GPS satellites. Once the receiver identifies a carrier, it begins "carrier tracking". This mode continuously compensates for the

²³ depending on the reference

²⁴ In times of hostilities to prevent enemy exploitation of a U.S. system.

²⁵ Because the NTC is located at a fixed location (Fort Irwin, CA), inaccuracies in the C/A-Code can be compared to on sight survey already available. This can provide a localized correction factor which will be applied automatically to the GPS receivers output. Accuracies to 1 meter are expected to be easily achieved at the NTC using only the C/A-Code and this technique. This type of application is currently being planned for an indirect fire simulation system discussed later

carrier's Doppler shift. After successfully beginning carrier tracking, the receiver synchronizes its spreading code with the satellite's. This is "code tracking". In the code tracking mode, the receiver can strip off and read the navigation/location message (NAV-msg). This message also helps estimate the satellite's future position and velocity, which aids in Doppler shift compensation for carrier tracking. DOD guarantees power at the receiver antenna which will be more than enough for any conceivable application at a Army test or training range.

4. THE USER EQUIPMENT SETS

There are three different types of GPS receivers fielded at present. These receivers, known as Equipment User Sets, differ in the way that they track the GPS signal and the way they process the information received. [Ref. 4] This directly affects their performance and accuracy. The user equipment sets are characterized by the "dynamics" of their host vehicles such as acceleration and "jerk" as well as by the sets' inherent accuracy. A low dynamic set is applicable at the NTC for fixed-base and man-portable operations. Low speed ground vehicles could also be sufficiently serviced by this type of receiver. A medium dynamic set is required for high speed ground vehicles and U.S. Army fixed and rotary wing aircraft. A high dynamic set is required for Air Force aircraft (U.S. and OPFOR).²⁶ The Low Dynamics Set tracks the necessary four satellites using only one hardware channel. This means that the set tracks only one satellite at a time and then combines the measurements when all four satellite pseudoranges have been measured. For this reason, low dynamic sets are called "sequential tracking" receivers. Medium Dynamic Sets (MDS) operate on two channels and high dynamic sets (HDS) operate on four or five. HDS calculate navigation information quickly, and offer the best anti-jamming performance, but usually cost 4 to 10 times as much as the LDS.

It should also be noted that receiver performance is graded on two criteria: Reaction Time (REAC) and Time-to-First-Fix (TTFF). REAC is the elapsed time from when a user equipment set is first turned on until the first "full accuracy" fix is presented. All user sets are designed to meet a minimum REAC 1 time, based on a C/A Code acquisition, but some are much faster than others. The most important criteria for the

²⁶ Most requirements at the NTC could be filled using Low Dynamic Sets (LDS) in conjunction with the modified C/A-Code. These receivers are relatively inexpensive (\$3-6 thousand per set depending on output format and desired "hardness"). and are readily available. The test ranges like TEC's at Hunter Liggett may need the accuracies of a high Dynamic Set in some applications.

NTC should be the TTFF. This is the elapsed time from when a fully warmed-up receiver is queried until the presentation of the fix. It usually takes about seven minutes for a receiver to warm-up fully.²⁷ Receivers currently on the market range in weight and power from a hand held, 2 pound receiver powered by six AA-alkaline batteries to a HDS at 50 pounds and 220 volts.

²⁷ In the NTC application, most receivers will be running continuously once put into daily operations.

III. POSITION/LOCATION REQUIREMENTS

Testing and training ranges use P/L for many vital functions needed to insure efficient use of time and materiel. Besides actual use in evaluation, these functions include behind the scenes control, safety and administration. This chapter will address the various requirements for P/L on an instrumented range in which GPS can play a significant part. It lists the measures of performance established by the OCs currently working at the NTC for each P/L requirements. How RMS and GPS compare under these measures will follow in chapter IV.

Because the NTC has a wide variety of P/L requirements, NTC requirements will be used in examples which apply similarly to all other instrumented ranges used for testing or training.

A. MEASURES OF PERFORMANCE (MOP)

With only one visit to the NTC, an outside observer can easily see that the overall control of this sophisticated training facility is only made possible by knowing the position of each of the player and OC elements. Even though the NTC prides itself on producing the most "free play" simulated battles ever produced for training, it takes an enormous amount of control to insure safety and effective use of expensive training time. Just getting the players and OCs into the correct positions to start the battles, is a challenge. Throughout the play of the exercises, it is vital to insure that all training elements stay within the guidelines of what they can and can not do as predefined by the NTC rules of engagement (ROE). [Ref. 5] The ROE are established for both the training unit and the OPFOR and include such instructions as limits in maneuver areas, what vehicles do when they are destroyed in the simulation, and guidelines on many safety issues. These would be almost impossible to enforce without accurate P/L. As the specific requirements for P/L are discussed below, performance of any P/L producing system is judged on the criteria of:

- SPEED (how fast is the location of player elements produced/updated)
- ACCURACY (how accurate are the locations produced)

- **COVERAGE** (how much of the range is covered by the system)
- **AVAILABILITY** (how many player elements can the system handle)

The following examples of P/L requirements will be addressed in these terms. The minimum and desired measures of performance (MOPs) are listed in the appropriate tables following the discussion.²⁸

B. CENTRAL INSTRUMENTATION SYSTEM (CIS)

The main function of the CIS is to provide the OCs with the ability to "look down" on the entire battlefield. This allows them to track the location of each of the combat and support elements. Even a sophisticated aerial view of Fort Irwin would not permit the detailed identification of player and OPFOR elements needed by the OCs. Without the CIS, it is estimated to take over 1000 OCs to keep track of these complex battles in the smoke, dust and confusion of the desert battlefields. Sitting in an air conditioned building, the TANGOS (CIS OCs) can depict, on a series of large computer screens, the entire battlefield with the location of each of the player vehicles, aircraft, and ground elements individually identified. Thanks to the sophisticated software of the central computer, they can zoom in to a specific location, run instant replays in fast forward, or look at just the particular type of elements they may wish to. This is an invaluable asset in training and control at the NTC. It gives the NTC the ability to do what it was designed to do, train units for combat. None of it could be possible without accurate P/L.

CIS MOPs averaged over the entire range are listed in the following table. Some of the more specific P/L requirements addressed later have a higher or lower performance standard when compared to average CIS MOPs. These are compared in the subsequent tables. The words "higher or lower" next to the MOPs refer to its comparison to the average case.

²⁸ Certain MOPs for testing ranges are modified for better accuracy [ref. 6] depending on the requirements of the test to be performed. Special equipment and/or techniques are employed to achieve these accuracies.

Table 3. MOPS (CIS)

MOP	MINIMUM	DESIRED
SPEED (standard)	Updated fix every 3 seconds	Updated fix every 1 second
ACCURACY (standard)	50 METER	1 METER
COVERAGE (standard)	90 % OF TRAINING AREA (no single area grater than 300 meters by 300 meters)	100 % OF TRAINING AREA
AVAILABILITY (standard)	500 ELEMENTS, 24 HOURS (no more than a 30 minute brake in coverage at any one time)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

C. MANEUVER AFTER ACTION REVIEWS

One primary application of (P/L) at the NTC, is recording unit locations for later playback by the OCs. This is done to support the, all important, After Action Reviews (AARs). AARs are conducted after each battle of the maneuver and live fire phase of training. In order to conduct these AARs effectively, exact locations of all vehicles, ground unit and aircraft throughout the battle needs to be available. At the battalion level and higher, AARs are produced to allow training unit leaders the opportunity to see exactly what happened during each phase of the battle. They are given a visual representations of actual battlefield P/L as recorded by the central computer. This is reproduced graphically for the training unit and the OPFOR on large viewing screens in air conditioned, five-ton expandable vans that travel to the battle site. Even though these large productions are not produced for lower echelons, AARs are conducted by the OCs at all levels, Computer depictions are not used at company and platoon level. Coordination between the OCs on the ground and the OCs in the CIS insures that an accurate picture of what actually took place can be used in the AAR. Without the ability to produce accurate P/L, it would be hard to convince leaders and trainers of the actual way events occurred. They often think things happened differently. Perspective is greatly clarified through these AARs.

Table 4. MOPS (AARS)

MOP	MINIMUM	DESIRED
SPEED (lower)	Updated fix every 10 seconds	Updated fix every 3 seconds
ACCURACY (lower)	100 METER	25 METER
COVERAGE (standard)	90 % OF TRAINING AREA (no single area grater than 300 meters by 300 meters)	100 % OF TRAINING AREA
AVAILABILITY (lower)	90 % of the elements that participated in the battle, 90 % of the battle duration (no more than a 30 minute brake in coverage)	ALL PLAYER ELEMENTS, 100 % of the duration (no break in coverage)

D. LIVE FIRE

Live fire training, by necessity, must be more controlled than the maneuver phase. During Live Fire, maneuver units fire live ammunition at a series of prepositioned targets. The targets are arrayed on a series of pop-up mechanisms. As one target goes down, a closer target pops up. This produces the effect of an advancing enemy. Firing units are allowed to maneuver, as they would in actual combat. Fixed target locations are known, but P L on the training unit is essential for safety and control. The target system itself records hits and misses. Automated safety, through the use of automated P L, provides the NTC with the ability to produce the most realistic live fire exercises ever used in training, yet still keep the margin of safety required to insure soldiers don't get hurt.

Table 5. MOPS (LIVE FIRE)

MOP	MINIMUM	DESIRED
SPEED (standard)	Updated fix every 3 seconds	Updated fix every 1 second
ACCURACY (standard)	50 METER	1 METER
COVERAGE (higher)	100 % OF THE LIVE FIRE TRAINING AREA (for safety, 100 % of Live Fire is required to be covered)	100 % OF TRAINING AREA
AVAILABILITY (higher)	100 % of the elements that participated in the battle, 95 % of the battle duration (no more than a 1 minute brake in coverage)	ALL PLAYER ELEMENTS, 100 % of the duration (no break in coverage)

E. INDIRECT FIRE

Producing realistic indirect fire effects is one of the most challenging tasks at the NTC. Realistic training requires this important aspect of combat be replicated. Currently, a system of "Fire Markers" dispatches a soldier in a specially equipped vehicle to the location of incoming artillery. He sets off ground and air burst simulators and assesses casualties that would be produced by the incoming rounds. This system is cumbersome, at best, and does not produce the desired results. A new Simulated Artillery Weapons Effects Instrumentation (SAWEI) is currently under development. This will be a new, GPS based system which will be carried on each player vehicle. It will allow a much more effective representation of artillery effects and will be more accurate in determining casualties produced. This system is expected to be fielded at the NTC within two years. P/L is also important in the calculation of indirect firing data. To compute accurate firing data, knowledge of exactly where the artillery units (all tubes) are is required. The CIS must have exact P/L to correctly compute firing data for comparison with the data produced by the firing elements. Indirect fire units are required to send their locations to the CIS, but evaluations of the firing units' accuracy can only occur if independent calculations are produced. Also, the CIS must use player unit P/L to determine what is within range of the calculated impact zone to accurately access casualties.

Table 6. MOPS (INDIRECT FIRE)

MOP	MINIMUM	DESIRED
SPEED (standard)	Updated fix every 3 seconds	Updated fix every 1 second
ACCURACY (standard)	50 METER	1 METER
COVERAGE (standard)	90 % OF TRAINING AREA (no single area grater than 300 meters by 300 meters), 100 % of the artillery firing unit locations.	100 % OF TRAINING AREA
AVAILABILITY (higher)	500 ELEMENTS, 24 HOURS (no more than a 1 minute brake in coverage at any one time during artillery preparation fires)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

F. CHEMICAL STRIKES

Chemical strikes are also a part of the battlefield actions at the NTC. Nonpersistent and persistent agents are simulated using CS (tear gas) by OCs on the ground. Areas effected by persistent agents need to be controlled long after the CS gas has dissipated. After an initial strike, recalculation of what areas are effected by chemical agents is done in the CIS by the Chemical Defense OC. Knowing who is in the effected area, for how long and when, can only be done with accurate P/L. Using OCs on the ground to constantly cover all chemically effected areas would be too labor intensive. If a unit crosses an effected area without taking the required precautions, casualties can be assessed from the CIS.

Table 7. MOPS (CHEMICAL STRIKES)

MOP	MINIMUM	DESIRED
SPEED (lower)	Updated fix every 10 seconds	Updated fix every 3 seconds
ACCURACY (lower)	100 METER	50 METER
COVERAGE (standard)	90 % OF TRAINING AREA (no single area effected by chemical agents grater than 300 meters by 300 meters)	100 % OF TRAINING AREA
AVAILABILITY (lower)	90 % OF PLAYER ELEMENTS, 80 % of the battle duration (no break in coverage greater than 30 minutes)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

G. MINEFIELDS

P'L is vital in the management and marking of minefields. Minefields are emplaced by both sides. Players are required to physically implant mock mines. Currently, when a minefield is emplaced by either side, the exact location and extent of the minefield is determined and controlled by an OC on the ground. He assesses casualties if an attempt is made to cross the minefield. Though players are required to report to the CIS where the minefields are emplaced, the reports are often inaccurate due to mistakes in the units map reading. Usually, OCs will record a minefield's exact location by using a manpack "B" unit. The "B" unit is taken to each corner of the minefield, locations being recorded in the CIS. This way the OCs can show the training unit, in the AAR, where they thought their minefields were verses where they actually were emplaced. Also, the OCs at the CIS can inform the OCs on the ground when a ground unit is approaching a minefield.

Table 8. MOPS (MINEFIELDS)

MOP	MINIMUM	DESIRED
SPEED (lower)	Updated fix every 10 seconds	Updated fix every 3 seconds
ACCURACY (lower)	100 METER	50 METER
COVERAGE (higher)	90 % OF TRAINING AREA (no single mined area grater than 50 meters by 50 meters)	100 % OF TRAINING AREA
AVAILABILITY (lower)	90 % OF PLAYER ELEMENTS, 80 % of the battle duration (no break in coverage greater than 30 minutes)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

H. OBSTACLES

Other battlefield obstacles (besides minefields) are required to be real. Such obstacles as tank ditches and wire are required to be fully emplaced. They perform their function of slowing or delaying the enemy without supervision of an OC. However, marking obstacles is performed in the same way as minefields for control. This requires P L. The most important information during an AAR when discussing why an obstacle plan was effective or ineffective, is knowing exactly where and how extensive the obstacles were.

Table 9. MOPS (OBSTACLES)

MOP	MINIMUM	DESIRED
SPEED (lower)	Updated fix every 10 seconds	Updated fix every 3 seconds
ACCURACY (lower)	100 METER	50 METER
COVERAGE (higher)	90 % OF TRAINING AREA (no single area effected by obstacles grater than 50 meters by 50 meters)	100 % OF TRAINING AREA
AVAILABILITY (lower)	90 % OF PLAYER ELEMENTS, 80 % of the battle duration (no break in coverage greater than 30 minutes)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

I. OBSERVER CONTROLLER NAVIGATION

It is critical for the OCs to move quickly across cluttered NTC battlefields without disrupting the free maneuver of the training units. They must do this in all types of weather and in any condition of daylight or blackness. OCs on the ground rely on the OCs at the CIS for assistance. CIS OCs have P/L on all field OCs, player/OPFOR units, obstacles and other disruptive features. They are in constant communication to aid in field navigation.

Table 10. MOPS (OC NAVIGATION)

MOP	MINIMUM	DESIRED
SPEED (standard)	Updated fix every 3 seconds	Updated fix every 1 second
ACCURACY (lower)	100 METER	50 METER
COVERAGE (higher)	90 % OF TRAINING AREA (All wire and tank ditches covered)	100 % OF TRAINING AREA
AVAILABILITY (higher)	90 % OF PLAYER ELEMENTS, 100 % of the OCs, 80 % of the battle duration (no break in coverage greater than 30 minutes)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

J. SAFETY

Because the battles are so unstructured, safety becomes a key factor over the entire time a units trains at the NTC. Experiences over the ten years the NTC has been in operation has demonstrated that life threatening emergencies are not at all uncommon in the normal conduct of training. When life is on the line and every second counts, exact location is more than just nice to know information. Accurate P/L also aids in the prevention of accidents. Life threatening mistakes, such as vehicles wandering into impact areas at Live Fire, are caught and corrected thanks to correct P/L. For these safety reasons, knowing the exact location of every element, at all times, is one of the jobs of the OCs at the CIS.

Table 11. MOPS (SAFETY)

MOP	MINIMUM	DESIRED
SPEED (standard)	Updated fix every 3 seconds	Updated fix every 1 second
ACCURACY (standard)	50 METER	1 METER
COVERAGE (standard)	90 % OF TRAINING AREA (no single area grater than 300 meters by 300 meters)	100 % OF TRAINING AREA
AVAILABILITY (standard)	500 ELEMENTS, 24 HOURS (no more than a 30 minute brake in coverage at any one time)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

K. LATER EVALUATION

Much of what goes on at the NTC is recorded for later evaluation and study that cannot be accomplished on sight. Not only does the training unit receive an extensive take-home package containing information, video tapes and computer print outs, but agencies from all services draw on data produced at the NTC to update and improve doctrine, tactics, logistics, materiel and training. Of course, the primary information recorded for these evaluations is the exact P/L of all elements during the various phases of the training. Many battles are fought by each training unit. What each element was doing at each moment and each location tells the story of how well each operation went. This, then, becomes the main data base for all subsequent evaluations and studies.

Table 12. MOPS (LATER EVALUATION)

MOP	MINIMUM	DESIRED
SPEED (standard)	Updated fix every 3 seconds	Updated fix every 1 second
ACCURACY (standard)	50 METER	1 METER
COVERAGE (standard)	90 % OF TRAINING AREA (no single area grater than 300 meters by 300 meters)	100 % OF TRAINING AREA
AVAILABILITY (standard)	500 ELEMENTS, 24 HOURS (no more than a 30 minute brake in coverage at any one time)	UNLIMITED NUMBER OF ELEMENTS, 24 HOURS (no break in coverage)

L. RMS AND MOPS

The current RMS system was designed to meet the minimum MOPs as listed above. Where "higher" than average performance levels are required (as indicated on the preceding tables), additional equipment is used. ²⁹ Even though RMS meets the minimum MOPs in every case, in no case does it meet the desired MOPs.

²⁹ additional "A" stations and more Central Computer capacity

IV. UTILIZATION OF GPS TO FILL POSITION/LOCATION (P/L) REQUIREMENTS.

Why should the Army use GPS based systems to fill position/location requirements on instrumented ranges such as Fort Hunter Liggett and the National Training Center? The current system does provide position/location to the extent stated above. The answer will be addressed in terms of lower cost, increased speed, better accuracy, more mobility, better coverage, more availability, and less complexity.

A. LOWER COST

Cost is a major consideration. Budgets are currently under attack and targeted for reduction. A GPS based system has the potential of saving a considerable amount of money for both the testing and training commands. A comparison of the cost of individual components of a GPS based system versus the RMS system shows the savings. The following tables are based on a current proposed upgrade to the NTC to provide a 1000 player element system. [Ref. 7]

Table 13. RMS COSTS

equipment	cost per unit	number required	total cost for a 1000 element system
"A" station	\$ 50,000	150 or more on large range	\$ 7.5 million
"B" unit	\$ 20,000 (current replacement costs at \$ 30,000)	each vehicle, aircraft, and weapon system	\$ 30 million
"C" station	\$ 1.5 million	2 or more per range	\$ 3 million
"D" station	\$ 30,000	relay stations used as needed	\$ 300,000 (for stock of 10)
Individual "B" unit (TEC also instruments each individual)	\$ 10,000	up to 1000 (depending on the number of individuals instrumented)	\$ 10 million
TOTAL			\$ 50.8 million

Table 14. GPS COSTS

equipment	cost per unit	number required	total cost for a 1000 element system
"A" station (mobile, RMS is fixed)	\$ 150,000	about 20 on large range (more expensive because of higher data rate, less needed because only one	\$ 3 million line of site required at each location on range.
GPS Receiver	\$ 5,000	one per instrumented element	\$ 5 million
telemetry equipment (part of a "B" unit other than P L)	\$ 5,000	one per instrumented element	\$ 5 million
telemetry interface	\$ 1,000	one per instrumented element	\$ 1 million
"C" station	\$ 2.5 million	only one needed	\$ 2.5 million
Individual unit	\$ 5,000	up to 1000 (depending on the number of individuals instrumented)	\$ 5 million
TOTAL			\$ 21.5 million

Table 15. SYSTEM COST COMPARISON

RMS EQUIP- MENT	TOTAL COMPO- NENT COST	GPS EQUIP- MENT	TOTAL COMPO- NENT COST	TOTAL GPS SAVINGS IN INI- TIAL AC- QUISITION
"A" STATIONS	\$ 7.5 million	"A" STATIONS	\$ 3 million	\$ 4.5 million
"B" UNITS	\$ 30 million	GPS RECEIVER, TELEMETRY EQUIPMENT, TELEMETRY INTERFACE (one each)	\$ 11 million	\$ 19 million
C STATIONS	\$ 3 million	C STATIONS	\$ 2.5 million	\$.5 million
RELAY STATIONS	\$.3 million	(non needed)	\$.3 million	\$ 0
INDIVIDUAL MAN-PACKS	\$ 10 million	INDIVIDUAL MAN-PACKS	\$ 5 million	\$ 5 million

The biggest savings comes from the reduced cost per instrumented element, GPS at about \$ 11,000 for the receiver, telemetry and interface units while RMS is at \$ 30,000 for an equivalent "B" unit. Additional savings can be seen in the reduction of required "A" stations by over 100 per range.

Of course, this is just a hypothetical case of the initial acquisition cost of an entire GPS based system vs an entire RMS system. The case at the NTC is; a 500 element system based in RMS has already been purchased and is in operation. Decisions to completely replace the current system with a GPS based system, phase GPS in over time or acquire additional RMS equipment can only be made by the command in charge. The scope of such a decision, however, should include an overall consideration of the needs of the Army in general in relation to P/L producing equipment. To do a life cycle

cost comparison of GPS vs RMS at the NTC as a bases for such a decision without taking into account other factors would not produce the desired results. Such considerations should include the proliferation of GPS in operational combat systems that will be brought to the NTC; the importance of standardization throughout the Army of similar testing and training systems; the importance of the increased capabilities of a GPS based system; the difficulty in using two different systems simultaneously on one range; goals and intentions of other services in relation to P/L producing equipment. (These issues and others will be addressed later in this thesis) Because of this complexity, there is a need for DoD level guidance to be given and detailed studies of cost vs value conducted.

Without much detailed study, however, a look at the previous tables shows that an entire GPS based system of 1000 elements has a lower initial cost than half an RMS system (required to bring the NTC from 500 to 1000 elements) This is enough to express the point of the vast difference in cost.

Of the \$ 20 million spent on maintenance each year at the NTC, over \$ 4 million is spent on maintaining instrumentation. Overall maintenance costs for a GPS system can only be estimated at the present time, but GPS promoters believe they could be cut in half because unit replacement costs are so much lower. Additionally, the cost of training maintenance personnel is expected to be much lower because of the reduction in complexity and the proliferation of GPS systems. It is expected to be much easier to find people with a background in GPS systems than RMS because of GPS's world wide use. GPS, overall, is a less expensive system because the large cost of the space and control segments are not calculated into the cost of the GPS user segment. These costs will remain the same no matter how many or how few GPS systems are fielded.

There are 26 ranges used by the testing and training agencies of the Army, Air Force and Marine Corps which are currently instrumented or planned for instrumentation in the near future. A study indicates a savings of over \$ 300 million over a ten year period by using GPS. [Ref. 7] Replacement of existing systems is planned as they reach the end of their current life cycle or as resources permit.

B. MUCH FASTER IN PRODUCING AND UPDATING P/L

With GPS, speed is a function of the number of receive channels used in the equipment. Sets using 1 or 2 channels (LDS and MDS) can easily exceed RMS speed MOP as listed in the tables above. Receivers using more channels have much increased speed

which can produce updates in the range of 10 times the RMS updates per second. [Ref. 7] With RMS, speed is also a function of the processing rate of the Central Computer. With GPS, P/L will be instantly available at the vehicle but must be processed for screen display at the CIS. This make speed comparisons somewhat invalid. Adding in the time it takes for RMS to be relayed to field users, GPS can be faster by a factor of three or more.

C. BETTER ACCURACY

For the testing community, the big advantage in a GPS equipped system is accuracy. With extra efforts and calculations the current RMS system can produce accuracies to within five meters, at best. TEC envisions a systems using GPS that can produce accuracies to within one meter or better. [Ref. 8] This would meet the desired MOP for accuracy.³⁰ This system could achieve the better accuracies needed for testing new weapon systems as well as the accompanying employment doctrine. At the NTC, 50 meter average accuracy is expected to drop to within 10 meter for moving vehicles. The desired 1 meter accuracy will be achieved for stationary systems such as artillery. GPS accuracy is changing rapidly. The ability to achieve better and better accuracy with GPS equipment is causing some difficulty in the development and acquisition of new systems. The Air Force contracted with RADSP0 Corporation in Sunnyvale, CA, to produce a highly accurate positioning system using GPS's P-Code. The product now ready for production costs over \$ 100,000 per set and can produce P/L only slightly more accurate than a \$ 5,000 receiver which uses the C/A-Code and the Differential Correction factor. Manufacturers of RMS components, Scientific Applications International Corporation (SAIC) in San Diego, CA, is now only producing advanced versions of this system at much higher costs. Though the new components are more accurate, the additional cost may cause an acceleration in the move away from that system.

D. COVERAGE AND MOBILITY

One major advantage of using GPS based P/L is the mobility it would give to the whole system. Instead of requiring units to travel to an instrumented range where P/L is produced from fixed "A" stations, a system using GPS could be taken to the training/testing unit anywhere in the world. A smaller number of "A" stations required

³⁰ This systems would use a combination of GPS and Inertial Navigation System (INS)

to establish a training center make it easier to develop the mobile training center concept. The function of "A" stations is also different in GPS based system. They act more as high speed data relay sights for P/L already produced and do not need to be surveyed. They can actually be mounted on vehicles that move with the battle.³¹ As GPS P/L becomes increasingly available worldwide, the location of training and testing could become unlimited. [Ref. 9] A prime example of the value of such a system has recently come to the foreground as the U.S. deploys forces to Saudi Arabia. Initially, the logistics of such a deployment has been the main focus of the leaders concerned. However, as time goes on and units become more settled, training exercises become increasingly important and are required to keep the units' "fighting edge". The OCs at the NTC say, "The best trained unit in the Army is the one that just left the NTC." As this thesis is being written, the NTC stands silent because the units that were scheduled to train there have been suddenly deployed for an indefinite period of time to the Middle East. Training ranges in Saudi Arabia, which just weeks ago were totally inaccessible to Army units, are now filled with U.S. forces becoming increasingly tired of sitting in the sand. How long will they be there? No one knows at this point, but talk of a commitment of years is not uncommon. If this becomes the case, the ability to rapidly instrument a training area at a distant location would be a big advantage. The Multi-national nature of this deployment and others also indicates the need for the ability to train on location. Even if the deploying units are individually at a high level of training, being able to coordinate combat actions with units from other nations could be greatly enhanced by quickly putting together training exercises.

The need for the National Training Center is not foreseen to evaporate anytime in the foreseeable future. It is still the Army's best place for training brigades and battalions. Even if instrumentation becomes highly mobile, the quality and number of the NTC's highly trained OPFOR could not be replicated at home stations. However, as the expense of moving large units to the NTC increases and budgets get tighter, the ability to supplement less and less frequent trips to the NTC with a training center that comes to the unit will become increasingly attractive.

³¹ A request for proposal will be released in October, 1990 for a system similar to this one. It is called the Mobile Automated Instrumentation Suite (MAIS).

E. AVAILABILITY

The current system at the NTC is being expanded to accommodate 1000 instead of 500 instrumented elements. [ref. 10] With GPS, P/L would be available to an unlimited number of participants. Range capacity would only be limited by the size of the central computer.

One inherent difference between P/L provided by the RMS system at the NTC and a GPS based system is the location the information is available. Although P/L is produced for each instrumented element with the current system, the only location where it is available, without being retransmitted, is the CIS. A B-unit on each vehicle transmits a signal which must be triangulated by at least 3 "A" stations, data analyzed at a central location (CIS) and a "fix" produced. The P/L is not available on at the vehicle. The triangulation, additionally, makes the current system, "A" station intensive. The RMS requires a large number of "A" stations which are inherently fixed to the training range. They must be accurately emplaced and verified by survey. They must also be positioned with redundancy in order to provide complete coverage throughout the range. If a single "A" station goes down, for whatever reason, it may effect the P/L of many vehicles in its area. With a GPS based system, each instrumented element would be equipped with a GPS receiver. This would make organic P/L available at the combat element. This data, along with other vehicle data, could be used onboard to determine battlefield status. As needed it would be transmitted to the CIS or provided to any other location where it would be used. The actual combat element itself would only need to have line of sight with a single "A" station to be able to transmit its location. If a "A" station went down, it would not effect the on-board capabilities of the GPS system. Because of the smaller number of "A" stations required, additional redundancy would be less expensive produce.³²

With each vehicle having organic P/L, evaluation of such things as indirect fire, minefield or chemical strike effects and assessments, could be simply calculated on board.

³² Transmission could be effectively done at VHF or UHF frequencies but would require a higher data rate than the current system because more information would be sent than just the time signal transmitted by the current RMS "B" unit.

F. LESS COMPLEXITY

Any system can be made to be complex. With a GPS instrumented range, however, components are less dependent on one another. Each vehicle knows its own location without requiring a series of "A" and "C" stations to produce it. In a GPS based system these stations only manage the information already produced. The increased capabilities and accuracies of GPS add to the complexity only in that they have more information to manage. Even with the additional information, it is a less complex system because it requires fewer actual components.

G. DEFINING REQUIREMENTS

A major problem in defining requirements for upgraded equipment at the NTC which might incorporate GPS, is the variety of interests from many different organizations. TRADOC, FORSCOM, INSCOM, CACTA,³³ the Branch Schools, the varied training units, the Air Force and Marine Corps,³⁴ all having different ideas; good ideas, but sometimes uncoordinated ideas. The command group at the NTC does an outstanding job with the difficult task of coordinating so many separate interests but it remains an ongoing challenge.

Coordination of requirements becomes especially difficult when so many different agencies use similar data for a variety of purposes. This is the case with P/L. An example can be seen in an indirect fire system currently planned for the NTC. The proposed system will be the kind described previously using organic P/L from a GPS based receiver. The proposed indirect fire system called the Simulated Artillery Weapons Effects Instrumentation (SAWEI) will incorporate GPS capabilities and will utilize the on station correction factor (Differential Correction) from survey in conjunction with LDS receivers as explained previously. Though it will be a very effective system for indirect fire simulation, it was designed only to address the indirect fire problem. Unfortunately, it will not, as currently designed, be able to interface with any other P/L producing system or provide information for any of the other P/L requirements. Some future proposed systems may be able to turn the data it produces into valuable information in satisfying their requirements.

³³ The Combined Arms Center for Training Analysis located at Fort Levenworth, Ka.

³⁴ Both the Air Force and the Marine Corps do major training in conjunction with NTC rotations

GPS is a giant step forward in concept, design and deployment in the field of navigation and position/location, offering a wide range of uses throughout the Armed Services. The GPS offices themselves, however, have not been tasked to come up with a comprehensive plan of utilization for all potential uses or users. They have been tasked with the job of providing the service and capabilities to those who are insightful enough to take advantage of it. Insightful program managers throughout the Services are scrambling to incorporate GPS into their systems under development. There are, however, few central policies or guidelines to help in this process. It is easy to see that a large system, with many subsystems, might end up with a variety of requirements that could be serviced by a central, GPS based input. Without coordination, the system might end up with several individual GPS receivers designed to service only a single subsystem, incapable of providing required input to others. Instrumented ranges may be subject to this problem. The current upgrade to the indirect fire system of the NTC, has been overseen by the Artillery Center and School, a TRADOC organization, to fill requirements established by the FORSCOM units training at the NTC. Other centers are similarly planning systems to improve combat simulations. Many of these systems require P/L in some form. Onboard P/L provided to all subsystems could help make the overall system less complex and less expensive. The ideal would be to have organic P/L on every vehicle which could be drawn on by any present or future subsystem. One GPS receiver system (costing much less than the current B-units) would satisfy this requirement and, if properly designed, have access ports for any future requirements. The NTC is not a lone player in the area of large, instrumented training centers but is definitely looked to as the leader and role model of what such a facility should be. Being the first of its kind and the largest in the world, the NTC sets the standard.

The U.S. is not the only NATO country interested in instrumented ranges. Many countries are watching the development of the Combined Maneuver Training Center at Hoensfeld which employs a GPS based system. Visitors from every NATO country (and many countries outside of NATO) have come to visit and study the NTC. As interest in instrumented testing and training centers grows, a coordinated effort to keep the systems similar in nature and user friendly would be a great advantage. It would reduce cost and complexity. A GPS system, providing organic P/L to each player element, would help fulfill this requirement.

V. USE OF GPS EQUIPMENT BY PLAYER UNITS

A. POSITION/LOCATION PRODUCING RECEIVERS

1. Line Units

So far this thesis has only addressed use of P/L by the instrumentation system of testing and training ranges. The other major issue here is that GPS produced P/L will soon be readily available to line units throughout the Army. Training units have already come to the NTC equipped with GPS receivers.³⁵ Incorporating multi-access GPS receivers into NTC vehicles could conceivably allow player access to P/L. This would replicate an actual capability player units will have as GPS receivers are fielded Army wide. Additionally, a variety of GPS equipped combat systems could draw on organically available PL for input.

Providing player units with P/L under the controlled conditions of the NTC will give the Army valuable information in developing more effective, GPS equipped systems for command and control, navigation and coordination.

2. OPFOR

As decision makers consider who should have access to P/L, a major question arises when discussing the OPFOR.

With an aging fleet of OPFOR vehicles³⁶ and discussions on their future replacements, built in instrumentation (GPS based) for the OPFOR vehicles of the future will be considered. If fielded in this manner P/L could be available to the OPFOR players themselves if a decision was made to give them access. Whether an onboard, integrated GPS system is ever fielded in U.S. vehicles or not, the U.S. units will soon have access to their own P/L as GPS equipped systems are fielded to maneuver units Army wide. The OPFOR, however, is a different situation. A conscious decision will have to be made, at some point, to give or deny the OPFOR access to P/L.

³⁵ The results of this fielding will be addressed in the following section.

³⁶ The OPFOR uses U.S. Sheridan tanks which have been converted to look like Soviet T 72 tanks and BMP armored personnel carriers. These vehicles are no longer in use in the operational U.S. fleet except for a single battalion of the 82nd Airborne Division. The NTC has become their primary user. They are no longer in production.

How, when and to what extent should they have access? The OPFOR goes to great lengths to insure their capabilities are no better or no worse than a front line Soviet Division. The Soviets are currently launching a system similar to GPS, but with some difficulty. It would not be unrealistic to say that a front line Soviet Division, such as the one the OPFOR is replicating, will soon have access to some kind of P/L producing assets. It is also not unrealistic to say, however, that it will be a long time after the fielding of U.S. systems before the Soviets have similar quality and availability. This issue may be lessened by recognizing the OPFOR has always been the best trained, best equipped Soviet unit in the world. To be able to fight an OPFOR which has access to their own P/L, could make it easier to face an enemy that does not.

B. OTHER SYSTEMS USING GPS INPUT

Information coming from the instrumented testing and training ranges will be a valuable resource to the Army, Air Force and Marine Corps as combat system using GPS capabilities are put into operation and used for the first time. Besides actual GPS receivers, many future command, control, and coordination systems will use GPS input.

1. Command And Control

The first such system scheduled for use at a major training center is the Marine Corps Position Locating Relay System (PLRS). Initial use of PLARS at the NTC was scheduled for August, 1990, but has been delayed due to "Desert Shield".³⁷ PLRS started out to be a joint project with the Army, but the Army has since dropped out in favor of an updated version of PLRS called EPLRS³⁸ Both systems are used by command elements to determine the location and status of subordinate units and other friendly forces in the area of operations. Both systems will have the capability of taking GPS P/L as input. The system will relay this information from all instrumented elements to designated users and is intended to greatly aid command, control, and coordination.³⁹ Whichever system is fielded first, it is certain that one of the primary function of GPS for the Army and Marine Corps will be command and control of subordinate forces.

³⁷ The code name used for the 1990, U.N. authorized actions against Iraq.

³⁸ EPLARS will have more functions and be more compatible to GPS, taking more advantage of GPS capabilities. The "E" represents "Extended".

³⁹ PLARS and EPLARS have other major communication functions besides providing location information but P/L is one of its main functions.

As with any new command and control systems, without training, they become a hindrance rather than an asset. Use of these systems at places like the NTC will insure units know how to use them in combat when the time comes. It will also help provide feedback to the developers of both the hardware and software of these systems to improve future versions.

2. Indirect Fire Support

To make indirect fire support work, the exact location of the firing unit, forward observer, and target must be known. The more accurate the information, the more accurate the fire support becomes. The current fire support computer, TACFIRE, can produce extremely accurate firing data in a very short period of time. It can receive digital data directly from the forward observer who currently punches in his location, by hand, which he, most often, takes from a map. Direct input from a GPS receiver would help with both accuracy and timeliness. Use of GPS to provide forward observer P/L will also provide more accurate target locations when using laser range finders. This information could also be sent digitally to the fire direction center.

Advanced TACFIRE and TACFIRE follow-ons will incorporate GPS. GPS provided P/L is expected to quickly become a vital part of upgraded indirect fire support equipment at all levels. GPS is also the locating source for a new self-laying howitzer under development. It is only natural to expect these system to be first tested on instrumented testing ranges and come to the NTC with training units as they are fielded.

3. Intelligence Systems

Much of Army intelligence is based on the location of friendly and enemy forces. A variety of GPS produced locations will be available from scouts, artillery units, organic military intelligence assets and maneuver units. Current intelligence computers are being designed to receive, digitally, this kind of information from multiple sources, process it, and disseminate the resulting products automatically. This process, which use to take hours, is foreseen to take minutes or seconds with the help of GPS produced P/L.

4. Electronic Warfare (EW)

EW units, much like artillery units, require exact location of emplaced assets to be effective. Direction finding equipment produces enemy transmitter locations only as accurate as its own P/L. As GPS receivers become more available, it is expected that

all current EW systems will be equipped with them. According to the Intelligence Center and School at Fort Huachuca, Arizona, all future tactical electronic warfare assets will roll off the assembly line pre-equipped with GPS capabilities. The first place these systems will be put into simulated combat, by the units that will rely on them in actual combat, will be the NTC and other instrumented training ranges.

C. TEST DEPLOYMENT RESULTS AND FINDINGS

In May, 1990, the First Brigade of the Fourth Infantry Division, home based at Fort Carson, Colorado, deployed to the NTC for a scheduled four week training rotation. The difference between this rotation and all others previously conducted at the NTC, was the use, by the training brigade, of GPS receivers. Their success during this rotation has been a major contributing factor in the decision to purchase and field such receivers Army wide. It also serves as an example of the of training unit use of P/L at a major training center.

1. Background

In 1989, the GPS Joint Program Office in Los Angeles, purchased 1000 small, hand-held GPS receivers for test and trial fielding across the services. 500 of these receivers were given to the Army and used, on a trial basis, in every major theater worldwide. The particular receivers purchased are called Small, Lightweight GPS Receivers (SLGRs).⁴⁰ The SLGR is produced by Trimble Navigation Corp. in Sunnyvale, California and is considered to be a commercial, "off the shelf", product.⁴¹ It uses the C/A-code and is considered to be an LDS. [ref. 11] The SLGR has two primary and two secondary modes.

The first primary mode produces a GPS derived "fix" of the receiver location (P/L). From the time the receiver is turned on to the production of an updated P/L, is about two minutes.⁴² During this warm up period, the receiver will display the last known position it produced. The receiver will also turn itself off after the fix is produced to save batteries. The second mode is the navigation mode. This mode will give the operator the azimuth and range from the current location, to the desired objective. In

⁴⁰ Pronounced Sluggers

⁴¹ It was not produced to DOD specifications

⁴² Time requirements and accuracies depend on the number of satellites in view of the receiver at the time the fix is taken.

this mode, the receiver will take 26 points along a desired route as input from the operator, read out location with reference to which two points the receiver is between, and give the direction and range to the next point. The other two modes are used simply for calculations of distance between points and do not use the GPS system to produce information. In these modes, the instrument acts more like a calculator in the polar coordinate mode than a GPS receiver, but can produce valuable information for planning the use of the other modes.

2. Results Of 4th Infantry Division Use At The NTC

The First Brigade of the Fourth Infantry Division (ID) deployed to the NTC in May, 1990, with a total of 240 SLGRs. This was not enough to fill all the Brigade's requirements, however, at various points during the rotation, the receivers were used at all levels of command down to squad/fire team. The receivers were also used by support units such as the direct support artillery unit, electronic warfare unit and the engineers. They were used in both the maneuver and live fire portions of the rotation. At the end of the rotation, all units, without exception, gave overall positive reports of their use. The after action report, on file at 4th ID and the Army Space Institute at Fort Levenworth, Kansas, reflects the following comments: [Ref. 12]

a. Prior Training

The units that used the SLGRs at the NTC had used them at Fort Carson in a "train up" exercise prior to coming to the NTC. Because of the fast pace of NTC battles, the familiarity and confidence the soldiers had in using the instruments insured their application at Fort Irwin. Soldiers that had not participated in the exercises at Fort Carson were unfamiliar with the use and capabilities of the receivers and were initially reluctant to use them.

b. Confidence In Leadership

Initial deployment in preparation for the first battle took place during a severe sand storm. One battalion commander commented, "Sand and dust were blowing so hard, we could hardly see where we were going. Use of the SLGRs insured that our initial placement of units was correct and according to our plans. When the wind stopped blowing and the soldiers could see they had been emplaced properly, it helped strengthen their confidence in the leadership."

c. Use Of The Various Modes

The mode most often used, during this rotation, was the first mode. This gave soldiers and leaders accurate P/L. "It was quick and easy to punch a button and read the numbers." "We used our maps, anyway, for reference and navigation and usually didn't have time to mess with punching in all the information required by the navigation mode but we constantly were pushing the button that gave us accurate P/L." "I did use the navigation mode in the sand storm, but I used the location mode the most. It was a fast way to get a fix on your location." "Even the guys I didn't trust to read a map could push a button and give me a location I could trust."

d. Problems

Sometimes soldiers became over confident with the GPS receivers. When asked their location, they would read it straight off the instrument which was set wrong or had not been updated with a current P/L. Some leaders complained that soldiers would give a location that was totally unrealistic, left over from the last battle or several grid squares away. When asked to check their coordinates, they would refer back to the device instead of looking at a map. This kind of problem was corrected with training.

The most complained about problems were the lack of availability and the windows of usage which are not yet 24 hour. These will be overcome in time with the future launches of additional satellites and the fielding of more equipment. There was one reported case of an argument over a conflict in data between the RMS and GPS. The problem arose over the claim that a unit had entered its own minefield according to RMS. The GPS data indicated that the unit was just outside the minefield. It was determined that the GPS data was the more accurate.

D. FUTURE PROCUREMENT

A full report of the test results, including more than a years testing of these receivers worldwide, is due out in October, 1990, and will be available through the GPS program office in Los Angeles. [ref. 13] The Army Program Manager says that this report will be mostly positive from the Army perspective. It will state that all units that used the receivers found them very capable instruments. It did not produce P/L as accurately or consistently as the larger sets used in earlier tests. The fact that these can be fielded down to a much lower echelon and in larger numbers due to lower costs, makes them

more desirable. The 100 meter accuracy was considered to be well within usable range for Army field use.

At present, the program office is writing the requirements for the production of the actual receiver that will be fielded down to squad team level Army wide. This set is being refereed to as the Precision, Small, Lightweight GPS Receiver (PSLGR). This set will meet DOD standards and will produce closer to 30 meter accuracies at a faster rate. Until these PSLGRs are fielded, the Army will continue to use the SLGRs as needed.⁴³

⁴³ Mid September, 1990, the Army purchased an additional 1000 SLGRs for use in the ongoing Operation "Desert Shield". Most of the, previously purchased, 1000, are already in use by U.S. units in Saudi Arabia,

VI. CONCLUSIONS AND RECOMMENDATIONS

A. GPS IS THE P/L PROVIDER OF THE FUTURE

The Global Positioning System, even though not yet fully deployed, has proven itself to be a dynamic, totally capable system, providing users with a global capability for accurate and timely position location. Though GPS is not yet capable of filling the 24 hour P/L requirements of the testing and training ranges throughout the Army, there is no reason to assume anything short of a full compliment of GPS satellites close to the 1992 time frame established by the U.S. Space Command. [ref. 14] This is well within the planning time frame for the deployment of future P/L providing systems. With increased emphasis on the use and implementation of GPS equipped systems, industry and the Army will be better capable of servicing GPS equipment. Operation and maintenance costs for a GPS based system will continue to decrease while capabilities will increase. On the other hand, the already aging RMS system will become less and less responsive to the innovations in training envisioned for the Army. The maintenance and unit replacement costs will become increasingly unattractive compared to GPS. The proliferation of GPS receivers has already caused the cost to drop well within the feasible range of a "per vehicle" consideration. Additionally, GPS has shown potential for far superior utility. The current systems have been invaluable in providing the Army with instrumented Testing and Training range capabilities over the past 12 to 15 years. These have been unequaled in performance and high tech applications for ground forces. There will be some reluctance, as always, to move to a new concept, new equipment or new applications. As stated in the introduction, the development of effective testing and training capabilities is one of the most important investments the Army makes. Changing it should not be taken lightly. There is an old saying in the Army which goes, "If it ain't broke, don't fix it!" There is another saying, however, that says, "If you can do it better, do it better! It may save your life someday." GPS is a way to do it better. The sooner we fully incorporate its capabilities, the better.

B. A COORDINATED APPROACH

A coordinated approach to all aspects of position/location on instrumented ranges will help avoid costly duplication of equipment and capabilities. Any employment of GPS receivers for instrumented training center use should be coordinated with other P/L requirements. This will help avoid using more than one GPS receiver per element.

As has been pointed out in the foregoing pages, there are many requirements for and many users of P/L on an instrumented testing or training range. Because these requirements and users fall under the jurisdiction of a multitude of agencies, many times, not even in the same major command, there is a great potential for duplication of effort. A simple realization by designers that there are other systems that could use the same P/L to satisfy different requirements at the same time, will automatically help in coordination. As one technical expert at TEC put it, "It is impossible to get your arms around all conceivable requirements at one time. In order to get anything done, you must limit your scope to a manageable range. Otherwise, nothing gets done." By the same token, if everyone is solving the same problem in a different way, scarce resources are wasted. In this case, it is appropriate to recommend a central agency or representative be established for coordination of P/L requirements. It could be established within TRADOC who fields most of the instrumented ranges, PM TRADE who oversees the acquisition of training support systems, or the GPS program office who oversees the acquisition of GPS receivers. It might even be established within FORSCOM who ultimately suffers or benefits from fielding of new systems. Where it is established is not as important as the fact that it is established; an agency responsible for looking at satisfying multiple needs with a single solution.

As requirements for the PSLGR, MAIS and SAWEI are currently being written, it would seem to be a prime time to consider jointly, operational, testing and training center requirements. A vision of the ideal solution would be to have all combat vehicles and weapon systems roll off the assembly line pre-equipped with a GPS receiver (or at least the mounts for one) that had output ports built in to accommodate all P/L requirements. It would just be a matter of plugging into an, already established, onboard system. This receiver would provide P/L interface for operational systems, fire control, command and control, and navigation. It would also be able to roll onto a testing or training range with the capability to interface directly with the range requirements for P/L. It may sound far fetched but the closer we get, the better we will be in all areas.

C. STANDARDIZATION AMONG TESTING/TRAINING FACILITIES IN THE PRODUCTION OF P/L

One of the major challenges we face in the highly mobile Army of today is standardization. It would be ideal if a soldier who was transferred from a unit which trains at the National Training Center in California to a unit that trains in Hoensfeld, West Germany and walk onto a similarly equipped range. Even though the tactics he became accustomed to in the desert vary from those of the Bavarian woods, he would feel familiar with the way the training ranges operate. To then have that soldier's unit called on to participate in simulated combat as part of an operational test of new equipment, and not need days or weeks to get use to another unfamiliar range operating system, would be ideal. Not all testing and training areas are fielded or upgraded at the same time. Requirements also differ from area to area. Instrumentation is always going to be somewhat different. Position/Locating devices, however, have potential for more standardization than currently planned. With GPS as a base, onboard P/L can become standardized. The increased accuracies required by the testing ranges can be achieved with modifications or enhancements of a basic system. Not only does standardization help the combat players, it also greatly reduces maintenance problems. Maintainers at one range would be dealing with the same issues and equipment as maintainers at other ranges. Cost also goes down as larger numbers of the same products are produced. Uniquely tailored systems only add to cost and complexity. As the CMTC at Hoensfeld is established, the NTC and other FORSCOM training centers upgraded, TEC expanded, MAIS contract let, P/L producing equipment is one thing they all have in common. It would reduce overall complexity if they are all constructed with common components.

D. GPS BASED P/L FOR PLAYER UNITS

One of the "manly" skills of a soldier over the history of the US Army has been his ability to read a map and find himself, even in the middle of the Mojave Desert of Fort Irwin. Many amusing hours have been spent at the CIS of the National Training Center by the observer controllers watching the display screen depicting a vehicle, totally lost, driving around in circles in the desert. But this is training. When they have finally found themselves, the soldiers who were lost will have learned valuable lessons for the next time they have to operate in the desert. To now propose giving the player units instant access to P/L might be in reality doing them a disservice; robbing them of an opportu-

nity to improve a skill that they might need in future combat. The transition to the idea that soldiers and units of the future are likely to have much more access to P/L than has ever been available before, may be hard to swallow for trainers. The truth is that the sooner soldiers and units get use to using this new capability, the better they are going to be able to incorporate it into their combat strength. One commander at the NTC made the point by stating, "Our ability to get along without our new technological gadgets in the case they aren't available doesn't scare me half as much as our lack of ability to get along with them if they are available." On one hand, designers of future upgrades to instrumented ranges can wait until the training units are able to bring P/L capabilities with them. Then they would not have to worry about planning for player unit access to P/L. We can go back to the idea of three or four GPS receivers in the same vehicle providing P/L on the same element. The smart way is to plan early, how to provide both with one.

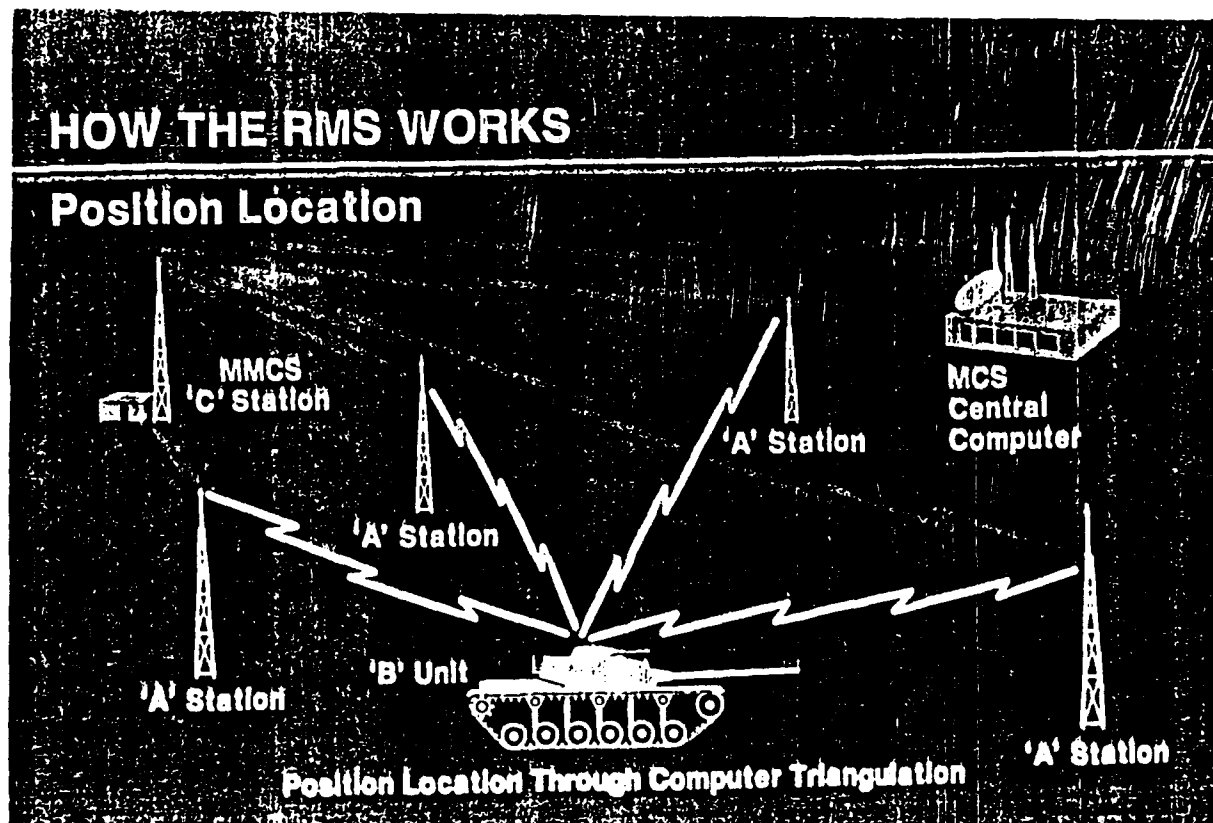
The issue of providing P/L to OPFOR units will have to be addressed at some point. The Soviets are fielding a similar system to GPS but with less success to date. The balance of who gets what will have to be a command decision but in any respect won't be an easy one. It will probably not be agreed upon by all elements involved no matter what the decision is.

E. USE OF GPS BASED SYSTEMS THROUGHOUT THE ARMY

Use of GPS based systems to instrument testing and training ranges throughout the Army will enhance the development and operational roles of GPS. As much as GPS can do for a training center like the NTC, the visibility of the NTC can do at least that much, if not more, for the GPS program. Even without the GPS space segment being totally deployed, users of the system have made significant achievements in applying and improving its capabilities. The more it is used, the more improvements are made. The work that has been done in developing ways to implement GPS into instrumented ranges has proven to have significant carry-over to operational combat application. The ability to refine GPS P/L using survey and inertial guidance is just one example. The more GPS is used, the more fully GPS will be seen as a combat multiplier. Just the exposure a place like the NTC or TEC can yield is a desirable by-product for the GPS program office in Los Angeles. Visibility of a GPS based instrumentation system at the NTC or TEC could impress thousands of player unit personnel as well as high ranking visitor

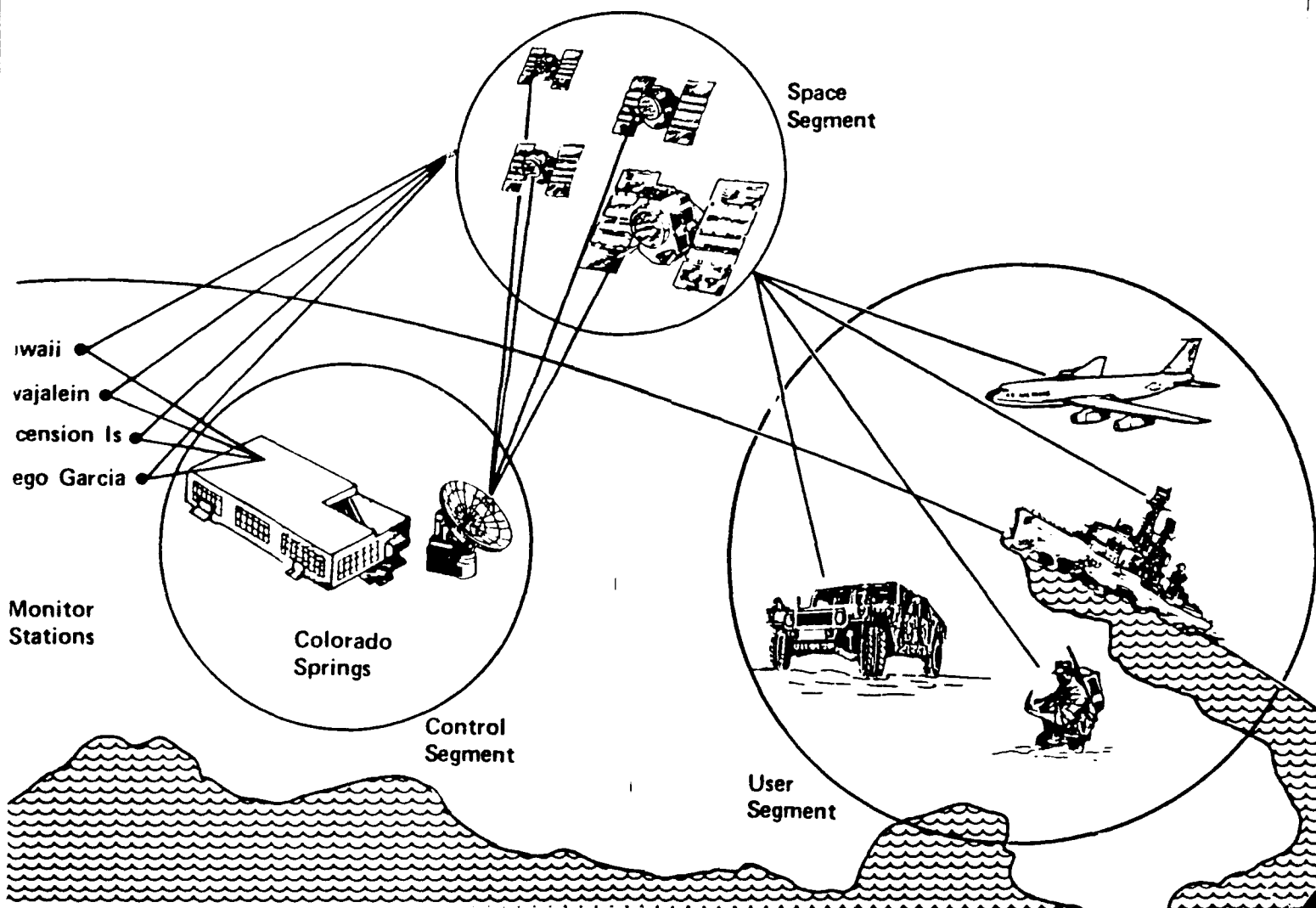
from around the world who come to visit. The GPS program office is very interested in doing whatever it can to encourage use of GPS at the Army testing and training centers.

APPENDIX A. THE REMOTE MEASURING SYSTEM (RMS)



APPENDIX B. THE GLOBAL POSITIONING SYSTEM (GPS)

GPS SYSTEM



APPENDIX C. GPS LAUNCH SCHEDULE

Table 16. GPS LAUNCH SCHEDULE

SATELLITE	LAUNCH DATE	STATUS SEP 90
	BLOCK I	
NAVSTAR 1	FEB 78	Failed Clock
NAVSTAR 2	MAY 78	Failed Clock
NAVSTAR 3	OCT 78	Clock needs regular update, still functional
NAVSTAR 4	DEC 78	Battery Problems, Near EOL but still functional
NAVSTAR 5	FEB 80	Attitude Control Failure
NAVSTAR 6	APR 80	Attitude Control Problems, Operational
NAVSTAR 7	DEC 81	Exploded on Pad
NAVSTAR 8	JUL 83	Operational
NAVSTAR 9	JUN 84	Operational
NAVSTAR 10	SEP 84	Operational
NAVSTAR 11	OCT 85	Operational
	BLOCK II	
NAVSTAR 14	FEB 89	Operational
NAVSTAR 13	JUN 89	Operational
NAVSTAR 16	AUG 89	Operational
NAVSTAR 17	OCT 89	Operational
NAVSTAR 19	NOV 89	Operational
NAVSTAR 20	FEB 90	Operational
NAVSTAR 18	APR 90	Operational
NAVSTAR 21	MAY 90	Operational
NAVSTAR 22	NOV 89	Operational
NAVSTAR 15	SEP 90	Operational
NAVSTAR 23	NOV 90	Planned
NAVSTAR 24-29	1991	Planned
NAVSTAR 30-35	1992	Planned
NAVSTAR 36-40	1993	Planned

APPENDIX D. DIFFERENTIAL CORRECTION FACTOR

This refers to a technique used with GPS C/A-Code to improve accuracy. It involves four steps:

- Taking a GPS reading at a survey site
- Comparing the GPS reading to the survey.
- Determining the difference and calculating a correction factor
- Transmitting the correction factor to local area users
- Applying the correction factor to GPS readings

Correction factors are only for local area use and apply only to satellites in view at the time the reading was taken at the survey site. This means the correction factor must be constantly updated and retransmitted. Using this technique, C/A-Code accuracy can approach 1 meter in ideal circumstances.

APPENDIX E. SMALL, LIGHTWEIGHT GPS RECEIVER (SLGR) SPECIFICATIONS

TransPak GPS *Hand-held GPS Receiver*

Performance Features

Three-dimensional position; 99 Waypoints; Cross Track Error;
Distance and Time Calculations; Range and Bearing; Land,
Sea and Air modes; GPS Status.

Options

- Rechargeable NiCad battery pack with 120V or 220V recharger.
- Remote antenna with 6 meter cable and mounting bracket
- Receiver mounting bracket

Physical Characteristics

Receiver:

Size: 6.5"W x 7.0"D x 2.0"H
Weight: 3.5 lbs (includes internal GPS antenna)
4.2 lbs when equipped with rechargeable
NiCad battery)
Power: 8 alkaline AA cell batteries (standard)
External 12V power adapter (standard)
8.4V rechargeable NiCad batt. (optional)
Display: 4 line, 20 character, back-lit LCD
Operating temp: 0° to +60°C
Storage temp: -40° to +70°C
Humidity: 95% non condensing
Casing: Splash proof, metal impregnated plastic

Remote GPS Antenna (optional)

Size: 6.0"H x 6.0"D
Weight: 3.5 lbs.
Operating temp: -40° to +70°C

Electrical Characteristics

General: Three channel; sequential, digital GPS receiver. Tracks up to 7 satellites.
Update rate: 1 second
Acquisition time: <2 minutes, 2-dimensional, typical.
3 minutes, 3-dimensional, typical.
Accuracy* (typical): Position: 15 meters RMS
Velocity: 0.1k RMS steady-state
Dynamics: 0-300 m/sec (0-650mph)
acceleration 2g, tracking.
Operating life: Standard battery pack—4 hrs continuous
Rechargeable NiCads—6 hrs continuous
(at 4 fixes/hour life is >50 hours)
Built In Antenna: Low profile, omni-directional
Remote Antenna: L1 circularly polarized

*Note: All GPS receivers are subject to degradation of position and velocity accuracies under Department of Defense imposed S/A (Selective Availability). Position may be degraded up to 100 meters 2 DRMS. The effect on velocity is yet to be determined.

Prices and specifications subject to change without prior notice

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